EEU44C04 / CS4031 / CS7NS3 / EEP55C27
Next Generation Networks

Wireless channel impairments and mitigation techniques

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Impairments and mitigation

IMPAIRMENTS

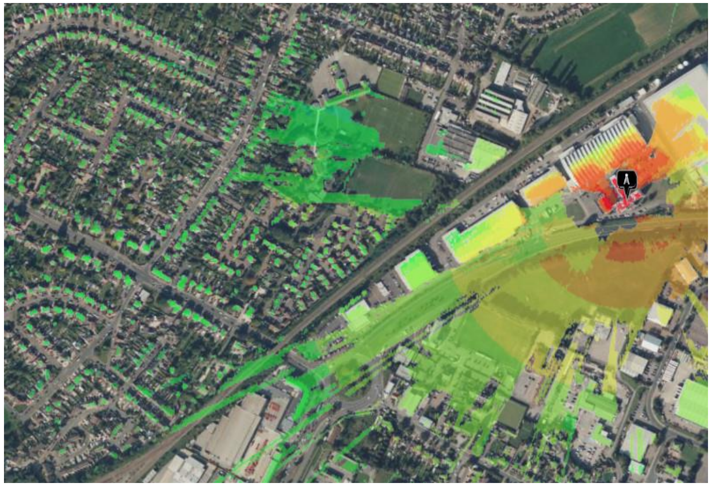
- Path loss
- Shadowing
- Fading
- Multipath
- Noise
- Interference

MITIGATION

- Diversity
- Directional antennas
- Coding and modulation
- Spread spectrum
- System-level mitigation: frequency and code planning, multiple access methods, etc.

Path loss

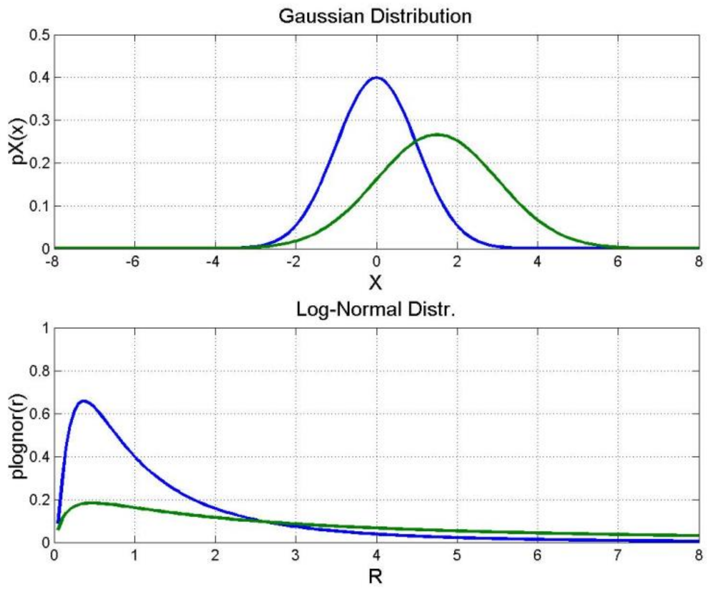
- Even when line-of-sight exists, signal attenuates with **distance**
- Path loss: attenuation undergone by an electromagnetic wave in transit between a transmitter and a receiver
- Roughly proportional to $1/d^2$, where d is the TX-RX distance



Source: https://cloudrf.com/

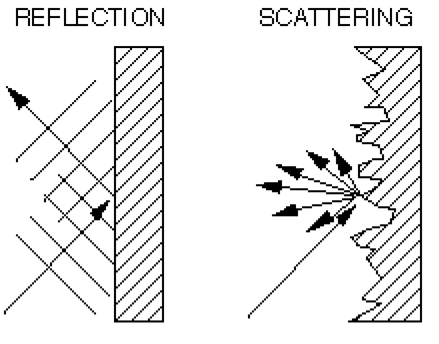
Shadowing

- Models attenuation from **obstacles**
- A random event, due to the random number and types of obstacles
- Typically modeled with a log-normal distribution
  - ✓ Local mean power, expressed in dB has a Normal (Gaussian) distribution



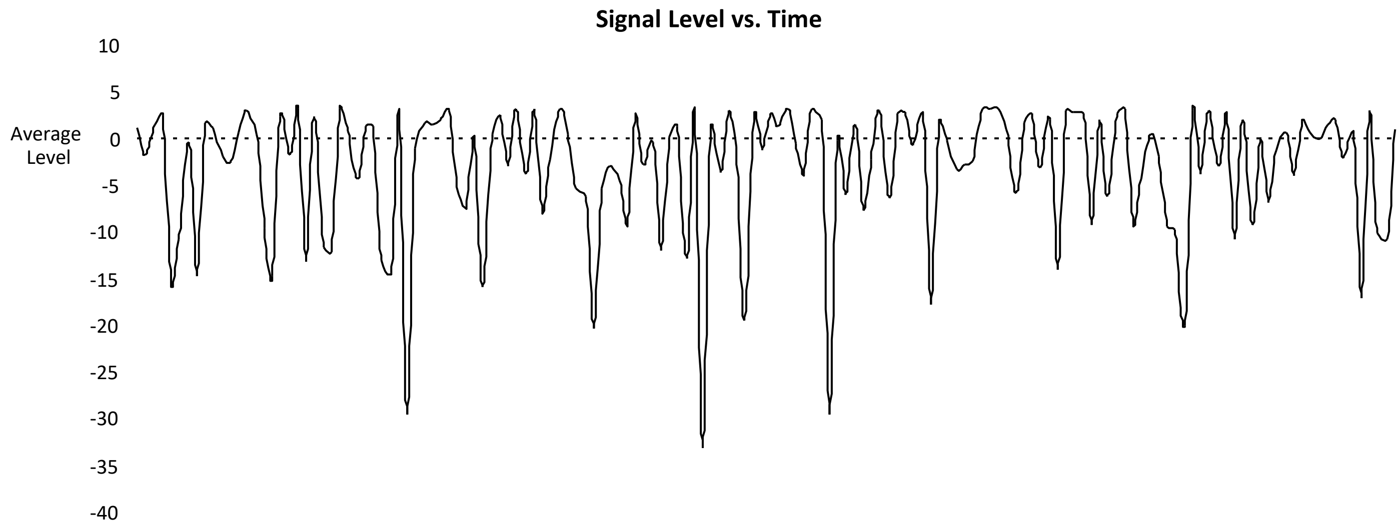
Multipath

- Due to **reflections and scattering**, multiple versions of the transmitted signal may arrive at the receiver
  - ✓ In severe cases, out-of-phase versions may cancel each other
- Delay spread: original signal is spread due to different delays of parts of the signal
- Leads to variability in frequency domain



Fading

- Quick variations in received power due to time-varying channel characteristics (related to TX/RX **mobility**)
- Various stochastic models (Rayleigh, Rician, etc.) for indoor and outdoor environments
- Leads to variability in time domain



Noise

- Unwanted signals added to the message signal
- May be due to signals generated by **natural phenomena** e.g., lightning, **or man-made sources** e.g., transmitting and receiving equipment as well as sparks in passing cars, wiring in thermostats, etc.
- Often modeled in the aggregate as a random signal in which power is distributed uniformly across all frequencies (white noise)
- Signal-to-Noise Ratio (SNR) often used as a metric in the assessment of channel quality

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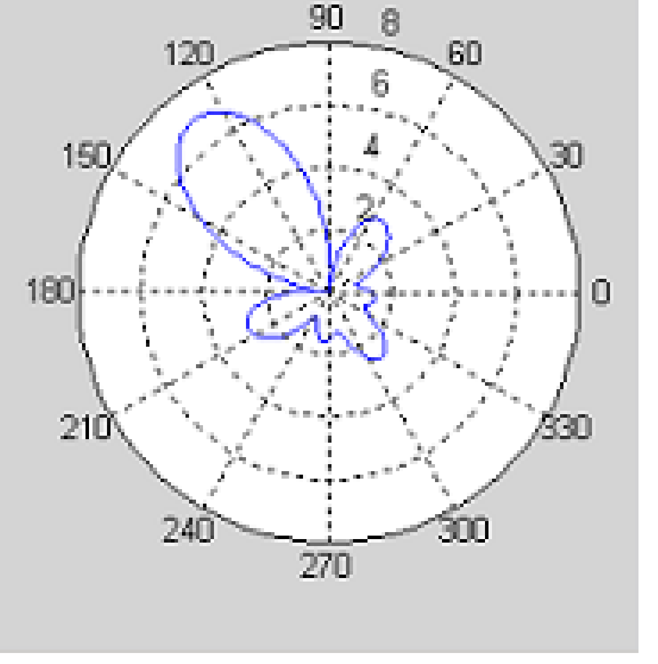
Diversity

- Combine **independently received** versions of the desired signal
- Spatial diversity: multiple antennas
- Frequency diversity: multiple frequencies
- Temporal diversity: repeated transmissions
- Polarization diversity: different polarizations

In spatial diversity, antennas are separated by at least half a wavelength

Directional antennas

- Antenna array elements arranged in a certain geometry
- By appropriately weighing the elements, one can **maximize the gain in one direction** while minimizing it in other directions
- Can be used to reduce interference (as well as probability of interception or jamming)



Example of antenna pattern produced by a 7-element, uniform (equally) spaced, circular array

Coding and modulation

e.g., to achieve same BER, QPSK uses less power than 16-QAM (lower SNR needed to get same error performance)

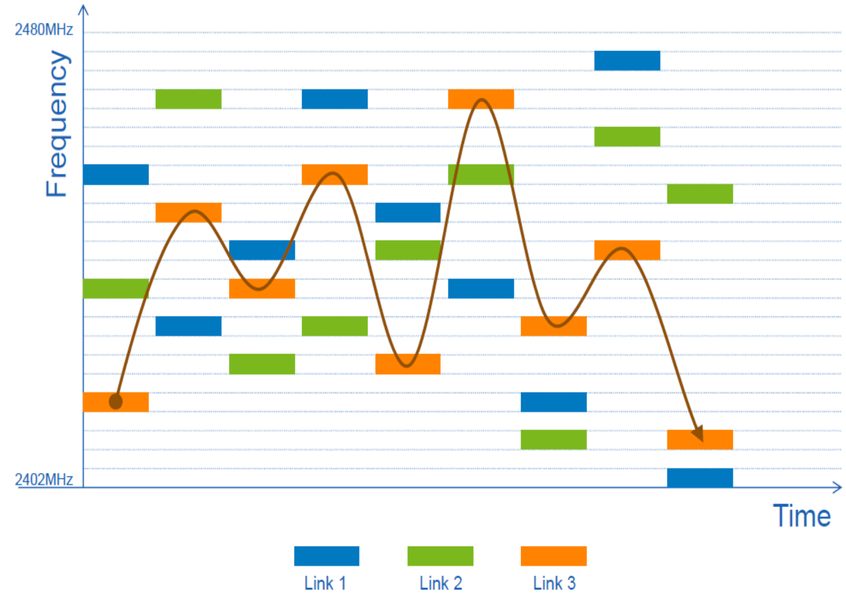
- Digital modulation schemes vary in…
  - ✓ Power efficiency – how much power is needed to transmit
  - ✓ **Spectral efficiency** – bits/second/Hz
  - ✓ Robustness – to multipath fading, noise, interference
- Multi-carrier modulation splits the bit stream into several lower bit rate streams, each sent using an **independent carrier frequency**
  - ✓ Frequency selective fading only affects some subcarriers, not the entire signal
- Forward error correction mitigates the effect of channel errors

Spread spectrum

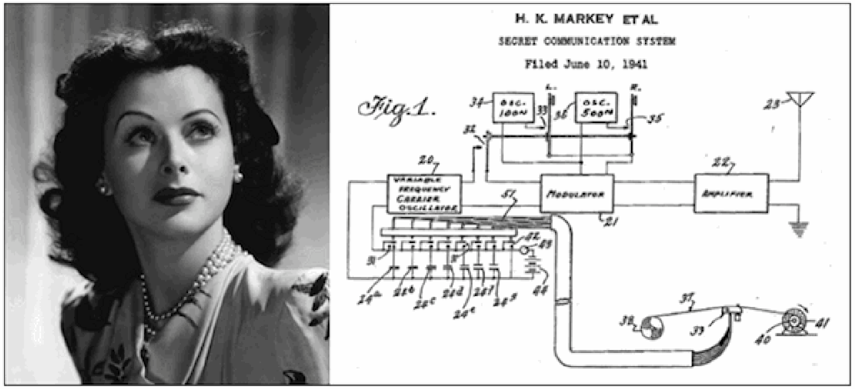
- Spread spectrum signals are distributed over a **wide range of frequencies** and then collected back at the receiver
  - ✓ These wideband signals are noise-like, hence difficult to detect or interfere with
- Initially adopted in military applications, for its resistance to jamming and difficulty of interception
- More recently, adopted in commercial wireless communications
- Frequency hopping and direct sequence spread spectrum variants

Frequency hopping

- Transmitter and receiver **hop among different frequency bands**, according to a pre-established and agreed hopping sequence



- Slow hopping (one frequency for several bit periods), fast hopping (hopping during a bit period)



Direct sequence spread spectrum (1)

- User bit stream is XORed with a chipping sequence

Spreading factor

$$s = \frac{t_b}{t_c}$$

Bit period

Chip period

$$t_c << t_b$$

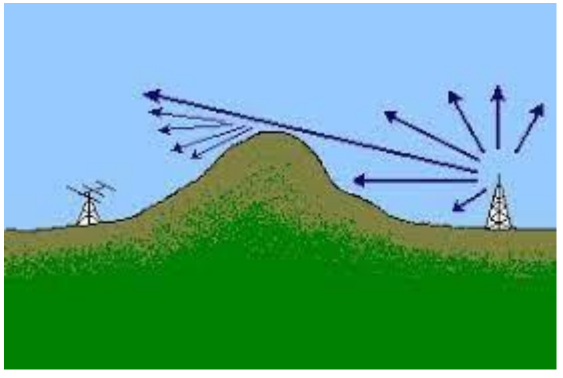
Spreading factors vary from 4 to 512 in FDD UMTS

Direct sequence spread spectrum (2)

- The **spreading factor** determines the bandwidth of the signal to be transmitted
  - ✓ Order of 10-100 for commercial applications
  - ✓ Up to 10,000 for military applications
- Example: IEEE 802.11 (Barker code)

- Frequency Hopping Spread Spectrum (FHSS) is simpler to implement than Direct Sequence Spread Spectrum (DSSS)
- DSSS is more resistant to fading and multipath and much harder to detect

- What is the most detrimental wireless channel impairment in Local Area Networks (LAN)?
- And in Wide Area Networks (WAN)?
- How about a hilly region?
- And for indoor environments?



What is the most detrimental wireless channel impairment in LAN? → **interference (access points are deployed close to each other)**

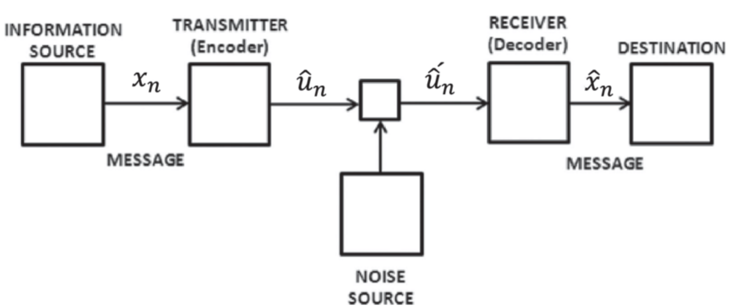
And in WAN? → **path loss, noise (base stations are deployed sufficiently far apart, but coverage area is large)**

How about a hilly region? → **shadowing "hiding" the transmitter (from the receiver's viewpoint)**

And for indoor environments? → **multipath due to many reflections of objects present in indoor environments**

Which of these coding rates is least beneficial in case of unreliable channel conditions?

- ❑ 1
- ❑ 1/3
- ❑ 1/2



Which of these coding rates is least beneficial in case of unreliable channel conditions?

- ✓ 1
- ❑ 1/3
- ❑ 1/2

Code rate = 1 means we add no redundancy to the information to be transmitted, which instead is needed to protect the information if the channel is unreliable, i.e., likely to introduce errors.

Explain the meaning of the following equation

$$C = B\log_2\left(1+\frac{S}{I+N}\right)$$

- Is it always beneficial to increase B? (consider that the noise power is $N=N_0B$, where N_0 is the noise's power spectral density). Motivate your answer.
- Is it always beneficial to increase the transmit power? (keep in mind the broadcast and shared nature of wireless medium). Motivate your answer.

Explain the meaning of the following equation

$$C = B\log_2\left(1+\frac{S}{I+N}\right)$$

C **= channel capacity [bps]**

B **= system bandwidth [Hz]**

S **= useful signal power [W]**

I **= interfering signal power [W]**

N **= noise power [W]**

- Is it always beneficial to increase B? (consider that the noise power is $N=N_0B$, where N_0 is the noise's power spectral density). Motivate your answer. **(there is a trade-off between increasing the bandwidth (more data rate potentially achievable but also more noise overall) and decreasing it (the converse))**

- Is it always beneficial to increase the transmit power? (keep in mind the broadcast and shared nature of wireless medium). Motivate your answer. **(there is a trade-off between increasing the transmit power (more coverage but also higher interference) and decreasing it (the converse))**